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Date: **9/2/11**

**TECHNICAL NOTE**



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## **MICE Spectrometer Solenoid: Overview and History**

## 1. Introduction

The following document will provide an overview of the two Spectrometer Solenoid magnets being fabricated by Wang NMR. Along with the overview, a history of the fabrication and testing of the magnets will be presented for context. A total of three magnet iterations have been tested (cooldown with some training) to date. The first magnet assembled and tested will be referred to as Magnet 1. The second magnet was run in two different configurations (with and without a single stage cooler). These iterations are referred to as Magnets 2A and 2B.

There are two key requirements for the training and acceptance testing of the magnets at the vendor as follows:

- Each of the five coils must be trained to 275 amps
- The cryocoolers must maintain the LHe in the cold mass (no boil-off)

Since neither of these requirements has been met for either of the magnets, a design modification plan has been developed (described in a separate document). As of now, LBNL has authorized the vendor to proceed with certain previously approved modifications, which have been incorporated in the design drawings and are currently under way.

## 2. Magnet History

### a. *Magnet 1*

The first magnet assembled and tested (Magnet 1) was built per the specifications of the original Wang NMR design report titled "Final Engineering Design for MICE Spectrometer Solenoid Magnets" and dated 9/6/06. The LHe cooling and recondensation circuit for this magnet consisted of a series of small diameter tubes that fed the recondensed LHe to the bottom of the cold mass and directed helium vapor from the top of the cold mass to the cryocooler recondenser cans. A cross section of the magnet showing this configuration is provided in Figure 1.

Upon cooldown of Magnet 1 to 4.2K, it was discovered that the cryocoolers were not recondensing helium due to blocked liquid and vapor return lines. It appears likely that the lines were blocked by frozen nitrogen. Prior to cooling down with LHe, the system is pre-cooled using LN. If the system is not fully purged of nitrogen using a thorough pump/purge procedure, then the remaining nitrogen can be frozen by the LHe and cause blockage of the cooling lines, as likely occurred in this case.

Even though the system was not recondensing helium, the magnet was cold enough to perform a series of training runs. The cold mass was refilled with LHe between runs. With all five coils running in series, a peak training current of 196 amps was reached. The training was discontinued when the available supply of LHe dewars ran out.

After the training runs were complete and the magnet was warmed up, Magnet 1 was disassembled in order to allow future modification of the recondensing circuit. This work

was carried out in parallel with the effort to assemble Magnet 2 with several design modifications.

*b. Magnet 2A*

The second magnet was assembled with a series of design enhancements. The primary changes included:

- replacement of the cooling circuit that originally used small diameter tubes with large diameter tubes connecting the condensing cans directly to the top of the cold mass
- addition of an LN reservoir connected to the shield to increase the shield cool down rate and to protect the HTS leads in the event of a power failure
- replacement of the thin, flexible copper straps that connected the shield to the 1st stage copper plate with thicker 1100 aluminum straps

A cross section drawing of Magnet 2A showing this modified configuration is provided in Figure 2.

Magnet 2A was cooled down, and the cryocoolers appeared to be recondensing helium; however, the magnet did not reach an equilibrium condition where there was no LHe boil-off. The training of the magnet commenced, and a current of 238 amps was reached at which point an open circuit was detected. After warm-up, the magnet tower was opened, and a burned out HTS lead was discovered (see Figure 3). Subsequent investigation and review of the temperature sensor logs indicated that the upper end of the HTS leads were inadequately cooled at their connection to the 1st stage copper plate.

*c. Magnet 2B*

A review committee was convened by MICE management in 11/09 in order to assess the magnet design and to recommend modifications. Per the committee's recommendation, a single-stage cooler capable of removing 170 watts at 55K was added to increase the cooling power at the upper end of the HTS leads and to help reduce the shield temperatures. A cross section of the magnet showing this configuration is provided in Figure 4, and the single stage cooler details are shown in Figure 5.

With the HTS lead temperature issue solved, Magnet 2B was trained in series to 258 amps when a coil lead was again found to contain an open circuit. Analysis of the coil voltage taps allowed the failure to be traced to the M2 coil somewhere inside of the cold end of the HTS leads. Training on the Center, E1 and E2 coils in series continued and reached a current of 270 amps.

Another observation made during the testing of Magnet 2B was that the three 2-stage coolers plus the single-stage cooler could not maintain a closed LHe system (per boil-off measurements). Subsequent analysis has indicated that the total recondensing power available from the three 2-stage coolers is less than the heat leak into the cold mass.

After warm-up, Magnet 2 was disassembled and the cold mass opened; the failed lead was located just inside the cold mass feedthrough. Analysis of the failure area indicated

that the conductor adjacent to the feedthrough will require the addition of extra copper to stabilize it against movement and to enhance conductive cooling. This improvement was carried out on Magnet 2B during the repair of the failed lead (Figure 6).

Finally, it was also noted that the passive quench resistors located within the cold mass of Magnet 2 had overheated at some point during the testing, resulting in bowing of the resistors and local charring of the adjacent G-10 insulating sheets. Subsequent analysis indicated that the resistors absorbed more heat than expected due to the failed lead. However, to prevent the possibility of a future occurrence, LBNL has designed, tested and is implementing a conductive cooling scheme for the quench resistors. Further details are provided in the quench analysis write up.

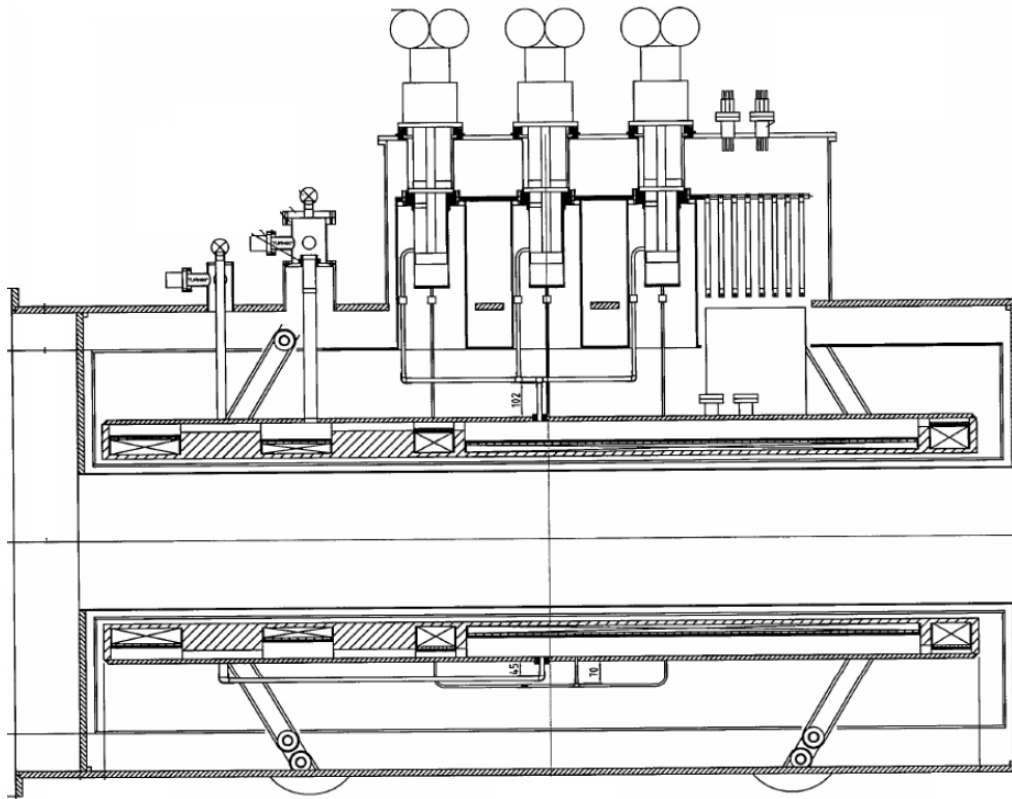


Figure 1: Cross section of Magnet 1.

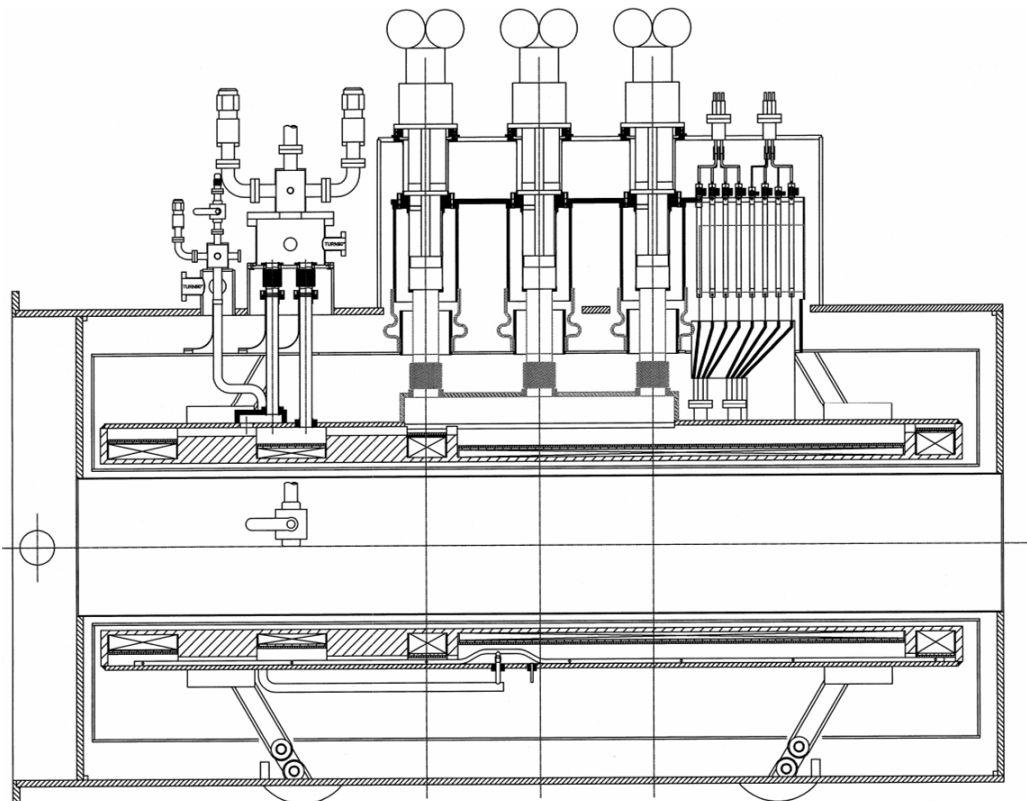


Figure 2: Cross section of Magnet 2A.

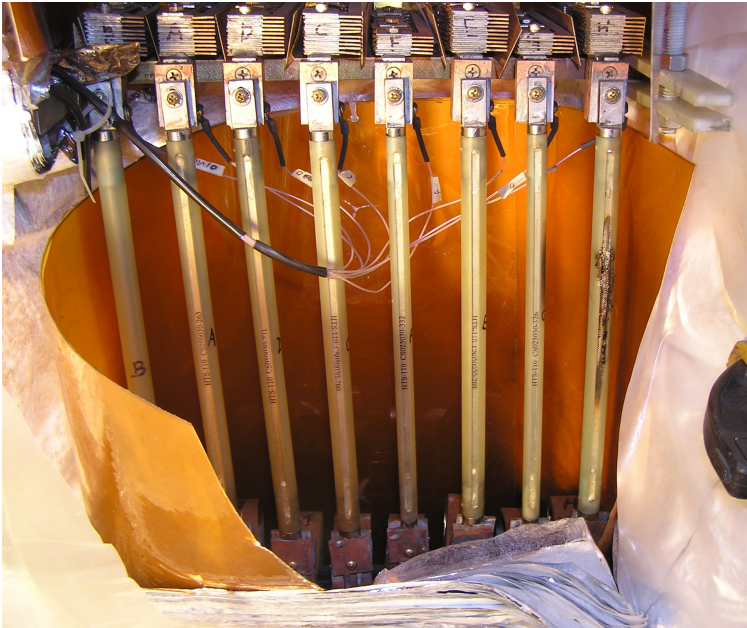


Figure 3: Burned out HTS lead in Magnet 2A (right).

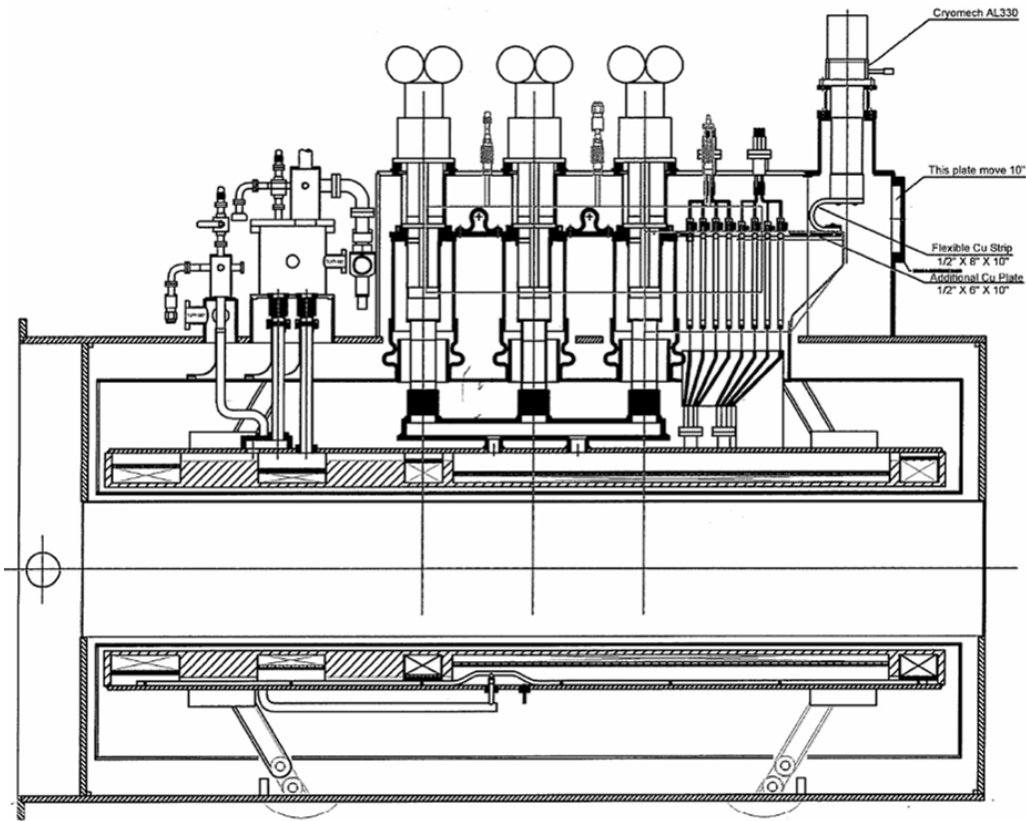


Figure 4: Cross section of Magnet 2B.

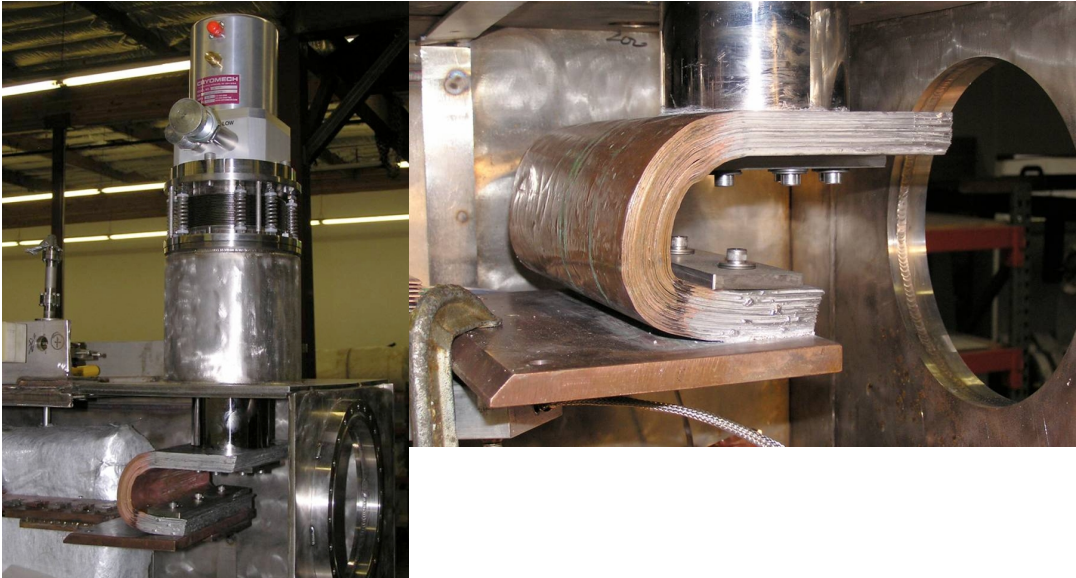


Figure 5: Magnet 2B single stage cryocooler (left), and the cooler connection (right).



Figure 6: Repair and stabilization of the Magnet 2B cold leads.